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(54) Method of detecting a deflated tyre on a vehicle.

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EP-A- 0 441 599
EP-A- 0 441 600
EP-A- 0 466 535
FR-A- 2 568 519
US-A- 4 777 611

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## Description

This invention relates to a method of detecting a deflated tyre on a vehicle suitable for cars, trucks or the like, and particularly to the system disclosed in for example French Patent Publication FR-A-2 568 519 and European Patent Publication EP-A-0 291 217.

These patent applications propose using wheel speed signals from the vehicle wheels, such as for example the signals from anti-lock braking systems which are multi-pulse signals or single-pulse signals for each rotation of each wheel. They compare the speed derived signals of the wheels in various ways to try to avoid false signals due to factors such as vehicle cornering, braking, accelerating, uneven and changing load etc.

The method disclosed in French Patent Publication FR-A-2 568 519 monitors the sums of the speeds of the diagonally opposed pairs of wheels for a long time or distance period so that it averaged out some of these errors. The result however was that the device operated very slowly taking many kilometres to sense pressure loss.

The method disclosed in European Patent Publication EP-A-0 291 217 substantially improved this situation by calculating the lateral and longitudinal accelerations of the vehicle using the same four-wheel speed signals and setting fixed limits above which the detection system was inhibited to avoid false signals due to cornering and acceleration. This system also suggested a correction for high vehicle speeds and for the first time introduced the ability to calibrate the system to suit the particular vehicle, and indeed the actual tyres fitted which themselves could have different properties from one another in respect of rolling radius. The calibration was carried out in straight line running, however, so whilst some vehicle conditions were allowed for the problems of detection during high speed running, cornering and braking under modern road conditions and particularly in higher performance vehicles could not be allowed for. The resultant system still needed to be inhibited for detection in a fair percentage of the vehicle running time. All attempts to improve this position resulted in loss of sensitivity of the system and/or loss of ability to sense which wheel or wheels was deflated if false signals were not to occur and made application of the system less effective.

An object of the present invention is to provide, in a system of the above type, the ability to sense deflations during higher levels of vehicle acceleration both laterally and longitudinally without false signals.

According to one the present invention there is disclosed a method of detecting a deflated tyre on a vehicle by comparing the rolling radii of the tyres by means of comparing angular velocity speed signals from wheel speed sensors one at each wheel. The method is characterised by, before the comparison of the signals is carried out, calculating corrected wheel speed signals for each of the second, third and fourth wheels giving corrections for a set of factors comprising vehicle speed, lateral acceleration and longitudinal (fore/aft) acceleration, the said corrections each comprising a constant for the factor concerned x the respective factor, the set of constants for each wheel being derived by taking the vehicle through a range of speeds, lateral and fore/aft accelerations and using multiple regression techniques and the respective factors being calculated from the set of uncorrected wheel speed signals so that comparison of the wheel speeds can be made without false signals from tyre deflections caused by speed, lateral or fore/aft acceleration induced tyre deflections.

Preferably in addition the corrections comprise a further constant x the square of the lateral acceleration; and/or a further constant x fore/aft acceleration x lateral acceleration; and/or a further constant x speed x lateral acceleration; and/or a further constant x speed x fore/aft acceleration; and/or a further constant x speed x lateral acceleration x fore and aft acceleration; and/or a further constant x speed squared and/or a further fixed constant.

Having carried out the corrections to the speed signals various comparisons between the speeds of the respective wheels can then be made depending upon the particular choice of ratios made.

The speed signals themselves may be multi-pulse signals such as are typical from ABS-type wheel speed generators or may comprise single-pulses from a wheel speed signal generator which gives a pulse for each revolution of the wheel. The speed signals may therefore be digital pulse signals or time periods timing the time for one rotation of each wheel and in that case a correction may be made to give the four wheel speeds at the same instant in time such as is described in our copending UK Patent Application No 9002925.7 dated 9 February 1990, published as EP-A-0 441 600 and US-A-5 192 929.

The comparison of the wheel speed signals preferably comprises subtracting the sum of the signals from one pair of diagonally opposite wheels from the sum of the signals of the other pair of diagonally opposite wheels, sensing when the magnitude of the result is between 0.05% and 0.6% of the mean of the sums and when that magnitude is in said range operating a warning device to indicate a tyre is partially or completely deflated.

In addition the comparison may comprise comparing the non-corrected signals from each of the four wheels in turn with the non-corrected signals for each of the other wheels, sensing when one of said signals is different from the average of all four signals by more than 0.1% and in the event of both this signal and the diagonals comparison being in the specified ranges then indicating that the tyre is partially or

completely deflated. These signals may be corrected by a simple set of controls to allow for variations between the tyre by means of calibration carried out at a constant speed in a straight line. These later comparisons provide means of detecting which particular wheel of the set is deflated and therefore the provision of an indication to the driver as to which wheel is concerned.

Further aspects of the present invention will become apparent from the following description by way of example only in conjunction with the attached diagrammatic drawings, in which:

Figure 1 is a schematic diagrammatic drawing showing a deflation warning device for a car with four wheels.

The apparatus shown in Figure 1 provides a deflation warning device for four wheels, 1, 2, 3, and 4, the wheels 1 and 2 being the front wheels and the wheels 3 and 4 the rear wheels of a car. Each wheel 1, 2, 3 and 4 has a wheel speed generating device associated with it. This may be of the toothed wheel type as used to provide a digital signal for electronic ABS equipment or merely the single-pulse type which generates a pulse one per wheel revolution. In this case the generator may be a single magnet attached to each wheel for rotation therewith and a stationary pickup mounted on the suspension.

The signals from each wheel are carried through cables 5 to provide input 6, 7, 8 and 9 to a central processing unit 10.

Four outputs from the central processing unit are connected to four warning indicators 12, 13, 14 and 15, one for each of the wheels respectively.

The central processing unit 10 is basically a computer and in the case where the vehicle already has an ABS-system fitted may be the same computer as the ABS-system. Alternatively a separate central processing unit may be provided. The central processing unit 10 monitors the various signals and compares them to determine whether or not it should give an outward signal to indicate that any tyre on the vehicle is deflated.

The central processing unit 10 can calculate substantially what the vehicle is doing using the four wheel speed signals. Firstly it can calculate the vehicle speed at any instant using either a single wheel as a reference or all four and calculating the mean. Secondly it can calculate the apparent longitudinal acceleration of the vehicle by comparing the angular velocity signals from the front and rear pairs of wheels with the forward speed calculated from the mean of the angular velocities of all four wheels. It can also calculate the apparent lateral acceleration of the vehicle comparing the angular velocity signals for the wheels on each side of the vehicle and then comparing them with the forward speed calculated from the mean of the angular velocities of all four wheels. Thus the central processing unit 10 can calculate substantially accurately what the vehicle is physically doing which allows it to then use a particular formula which will be described below to correct the wheel speed signals for three of the wheels allowing for what the vehicle is doing.

Having obtained the four corrected wheel speed signals C1, C2, C3 and C4 the system can then calculate an error signal dT by comparing the angular velocities of the wheels according to the formula

$$dT = 2 \times \frac{(C1-4 \; - \; C2-3)}{(C2-3 \; + \; C1-4)} \times 100$$

where

$C1 - 4 = C1 + C4$ and $C2 - 3 = C2 + C3$.

This error or dT signal is monitored and the processing unit senses and indicates a deflation if the signal is greater than 0.05% and less than 0.6%.

The next step is to find which tyre is punctured.

The unit carries out this determination by looking at the difference between each wheel's non-corrected angular velocity in turn and the average speed of the four wheels using non-corrected speeds C1, C2, C3 and C4. If the difference between any one wheel and the average is more than 0.1% a second signal is generated to indicate which wheel is partially or substantially deflated.

This check may be performed using speed signals corrected to allow for tyre differences in the set of tyres by means of simply correcting. This is done by running the vehicle in a straight line at a constant speed and deriving correction factors.

As mentioned above this system detects whether or not a puncture exists using the corrected wheel speed C2, C3 and C4 corrected on the basis of C1 being itself correct. The correction in speeds is achieved by using a formula which comprises:

C = A1 x speed$^2$ + A2 x speed + A3 x (lateral acceleration)$^2$ + A4 (lateral acceleration) + A5 (fore/aft acceleration) + A6 x speed x lateral acceleration + A7 x speed x fore and aft acceleration + A8 x lateral acceleration x fore and aft acceleration + A9 x speed x lateral acceleration x lateral fore and aft acceleration + A10

where

A1 to A10 are constants for the particular wheel concerned.

The constants A1 to A10 are determined by a prior calibration for the vehicle and provide corrections for the wheel speed concerned to allow for changes in rolling radius caused by changes in weight on the particular wheel concerned by the effects of acceleration, braking, etc on the vehicle. The constants also correct for the particular vehicle concerned for differences due to tyre growth due to wheel speed.

The constants are found by a practical method by means of using a calibration routine which comprises driving the vehicle through a full range of accelerations both longitudinally and laterally in both directions of left and right turns and covering all other pos-

sible vehicle use conditions.

This can readily be achieved by driving the vehicle on a mixed road test and the central processing unit constantly monitors the effects on wheel speeds and records them. The entire top range results are then ignored to avoid later errors, i.e. the top 5 or 10% of acceleration figures.

The central processing unit is then set into a multiple regression analysis procedure using any of the standard techniques to calculate the ten constants A1 to A10 which gives it the necessary correction system to make sure that wheel speeds are made independent of extraneous factors such as weight transfer in the vehicle and cornering and acceleration.

It should be noted that it is not necessary to calibrate each vehicle in a particular type by this method and the central processing unit may be reprogrammed for that model of vehicle because it allows for the basic vehicle characteristics which are set by its body shape, centre of gravity position and suspension characteristics. In some circumstances similar calibration can be used for more than one type of vehicle without recalibrating but the basic principal of the invention is that it provides the ability to correct wheel speeds for all vehicle characteristics in use.

This correction system may be used with other wheel speed comparisons to provide deflation warning and can if necessary be used for correction of wheel speeds for calculation of other vehicle factors, such as for example torque control.

## Claims

1. A method of detecting a deflated tyre on a vehicle by comparing the rolling radii of the tyres by means of comparing angular velocity speed signals from wheel speed sensors one at each wheel characterised by, before the comparison of the signals is carried out, calculating corrected wheel speed signals for each of the second, third and fourth wheels giving corrections for a set of factors comprising vehicle speed, lateral acceleration and longitudinal (fore/aft) acceleration, the said corrections each comprising a constant for the factor concerned times the respective factor, the set of constants for each wheel being derived by taking the vehicle through a range of speeds, lateral and fore/aft accelerations and using multiple regression techniques and the respective factors being calculated from the set of uncorrected wheel speed signals so that comparison of the wheel speeds can be made without false signals from tyre deflections caused by speed, lateral or fore/aft acceleration induced tyre deflections.

2. A method according to Claim 1 characterised in that the corrections comprise a further constant times the square of the lateral acceleration.

3. A method according to Claim 1 or 2 characterised by a further constant times fore/aft acceleration times lateral acceleration.

4. A method according to any one of Claims 1, 2 or 3 characterised by a further constant times speed times lateral acceleration.

5. A method according to any one of Claims 1, 2, 3 or 4 characterised by a further constant times speed times fore/aft acceleration.

6. A method according to any one of Claims 1, 2, 3, 4 or 5 characterised by a further constant times speed times lateral acceleration times fore and aft acceleration.

7. A method according to any one of Claims 1 to 6 characterised by a further constant times speed squared.

8. A method according to any one of Claims 1 to 7 characterised by a further fixed constant.

9. A method according to any one of Claims 1 to 8 characterised by a comparison of the corrected wheel speed signals comprising subtracting the sums of the signals from one pair of diagonally opposite wheels from the sum of the signals from the other pair of diagonally opposite wheels, sensing when the magnitude of the result is between 0.05% and 0.6% for the mean of the sums and when the magnitude is in said range operating a warning device to indicate the tyre is partially or completely deflated.

10. A method according to Claim 9 characterised by additionally comparing the non-corrected signals from each of the four wheels in turn with the non-corrected signals for each of the other wheels, sensing when one of said signals is different from the average of all four signals by more than 0.1% and in the event of both said signals being present indicating that the tyre is partially of completely deflated.

11. A method according to Claim 9 characterised in that the signals are corrected relative to one another based on constants derived from straight line running of the vehicle at a single speed.

## Patentansprüche

1. Ein Verfahren zum Nachweisen eines zumindest

teilweise entlüfteten Reifens an einem Fahrzeug durch Vergleichen der Rollradien der Reifen, indem Winkelgeschwindigkeitsdrehzahlsignale von Radgeschwindigkeitssensoren, einer an jedem Rad, verglichen werden,
dadurch gekennzeichnet,
daß, bevor der Vergleich der Signale durchgeführt wird, korrigierte Radgeschwindigkeitssignale für jedes der zweiten, dritten und vierten Räder berechnet werden, die Korrekturen für einen Satz von Faktoren ergeben, die Fahrzeuggeschwindigkeit, laterale Beschleunigung und longitudinale (Vorn/Hinten-)Beschleunigung umfassen, wobei die Korrekturen jeweils eine Konstante für den betroffenen Faktor multipliziert mit dem jeweiligen Faktor umfassen, daß der Satz von Konstanten für jedes Rad abgeleitet wird, indem das Fahrzeug durch einen Bereich von Geschwindigkeiten, lateralen und Vorn/Hinten-Beschleunigungen geführt wird und Mehrfachregressionstechniken verwendet werden, und daß die jeweiligen Faktoren aus dem Satz unkorrigierter Radgeschwindigkeitssignale berechnet werden, so daß ein Vergleich der Radgeschwindigkeiten ohne falsche Signale von Reifenverformungen durchgeführt werden kann, die durch von Geschwindigkeit, lateraler oder Vorn/Hinten-Beschleunigung hervorgerufenen Reifenverformungen verursacht werden.

2. Ein Verfahren nach Anspruch 1,
dadurch gekennzeichnet,
daß die Korrekturen eine weitere Konstante multipliziert mit dem Quadrat der lateralen Beschleunigung umfassen.

3. Ein Verfahren nach Anspruch 1 oder 2, gekennzeichnet durch eine weitere Konstante multipliziert mit der Vorn/Hinten-Beschleunigung multipliziert mit der lateralen Beschleunigung.

4. Ein Verfahren nach einem der Ansprüche 1, 2 oder 3,
gekennzeichnet durch eine weitere Konstante multipliziert mit der Geschwindigkeit multipliziert mit der lateralen Beschleunigung.

5. Ein Verfahren nach einem der Ansprüche 1, 2, 3 oder 4,
gekennzeichnet durch eine weitere Konstante multipliziert mit der Geschwindigkeit multipliziert mit der Vorn/Hinten-Beschleunigung.

6. Ein Verfahren nach einem der Ansprüche 1, 2, 3, 4 oder 5,
gekennzeichnet durch eine weitere Konstante multipliziert mit der Geschwindigkeit multipliziert mit der lateralen Beschleunigung multipliziert mit der Vorn-und-Hinten-Beschleunigung.

7. Ein Verfahren nach einem der Ansprüche 1 bis 6, gekennzeichnet durch eine weitere Konstante multipliziert mit dem Quadrat der Geschwindigkeit.

8. Ein Verfahren nach einem der Ansprüche 1 bis 7, gekennzeichnet durch eine weitere feste Konstante.

9. Ein Verfahren nach einem der Ansprüche 1 bis 8, gekennzeichnet durch einen Vergleich der korrigierten Radgeschwindigkeitssignale, welcher umfaßt, daß die Summen der Signale von einem Paar diagonal gegenüberliegender Räder von der Summe der Signale vom anderen Paar diagonal gegenüberliegender Räder subtrahiert wird, daß wahrgenommen wird, wenn der Betrag des Ergebnisses zwischen 0.05 % und 0.6 % für den Mittelwert der Summen liegt, und daß, wenn der Betrag in dem Bereich liegt, eine Warnvorrichtung betätigt wird, um anzuzeigen, daß der Reifen teilweise oder vollständig entlüftet ist.

10. Ein Verfahren nach Anspruch 9,
dadurch gekennzeichnet,
daß zusätzlich die nicht-korrigierten Signale von jedem der vier Räder ihrerseits mit den nicht-korrigierten Signalen für jedes der anderen Räder verglichen werden, daß wahrgenommen wird, wenn sich eines der Signale vom Durchschnitt aller vier Signale um mehr als 0.1 % unterscheidet, und daß in dem Fall, daß beide Signale vorliegen, angezeigt wird, daß der Reifen teilweise oder vollständig entlüftet ist.

11. Ein Verfahren nach Anspruch 9,
dadurch gekennzeichnet,
daß die Signale relativ zueinander korrigiert werden, und zwar gestützt auf Konstanten, die von einem Geradeausfahrbetrieb des Fahrzeugs bei einer einzigen Geschwindigkeit abgeleitet werden.

**Revendications**

1. Procédé de détection d'un pneumatique dégonflé sur un véhicule, par comparaison des rayons de roulement des pneumatiques effectuée par comparaison de signaux de vitesse angulaire provenant de capteurs de vitesse de roues à raison d'un par roue, caractérisé, avant la comparaison des signaux, par le calcul de signaux corrigés de vitesse de roues pour chacune des seconde, troisième et quatrième roues, par utilisation de corrections correspondant à un ensemble de fac-

teurs comprenant la vitesse du véhicule, l'accélération latérale et l'accélération longitudinale (avant-arrière), les corrections comprenant chacune une constante correspondant au facteur concerné multipliée par le facteur respectif, l'ensemble de constantes destinées à chaque roue étant dérivé par déplacement du véhicule dans toute une plage de vitesses, d'accélération latérale et d'accélération avant-arrière et par utilisation de techniques de régression multiple, les facteurs respectifs étant calculés à partir de l'ensemble de signaux de vitesse non corrigés de roues afin que la comparaison des vitesses de roues puisse être effectuée sans signal erroné dus au fléchissement des pneumatiques provoqué par la vitesse, l'accélération latérale et/ou l'accélération avant-arrière.

2. Procédé selon la revendication 1, caractérisé en ce que les corrections mettent en oeuvre une constante supplémentaire multipliée par le carré de l'accélération latérale.

3. Procédé selon la revendication 1 ou 2, caractérisé par une constante supplémentaire multipliée par l'accélération avant-arrière et multipliée par l'accélération latérale.

4. Procédé selon l'une des revendications 1, 2 et 3, caractérisé par une constante supplémentaire multipliée par la vitesse et multipliée par l'accélération latérale.

5. Procédé selon l'une des revendications 1, 2, 3 et 4, caractérisé par une constante supplémentaire multipliée par la vitesse et multipliée par l'accélération avant-arrière.

6. Procédé selon l'une des revendications 1, 2, 3, 4 et 5, caractérisé par une constante supplémentaire multipliée par la vitesse, multipliée par l'accélération latérale et multipliée par l'accélération avant-arrière.

7. Procédé selon l'une des revendications 1 à 6, caractérisé par une constante supplémentaire multipliée par la vitesse au carré.

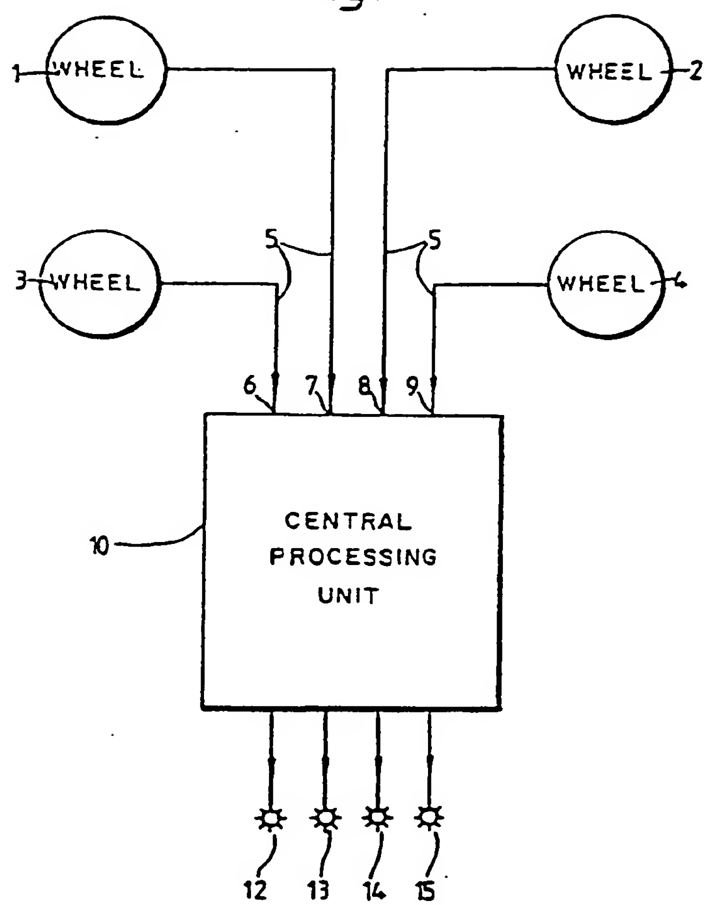
8. Procédé selon l'une des revendications 1 à 7, caractérisé par une constante fixe supplémentaire.

9. Procédé selon l'une des revendications 1 à 8, caractérisé par une comparaison des signaux corrigés de vitesse de roues comprenant la soustraction des signaux d'une paire de roues opposées en diagonale de la somme des signaux de l'autre paire de roues opposées en diagonale, la détection, lorsque l'amplitude du résultat est comprise entre 0,05 % et 0,6 %, de la moyenne des sommes et, lorsque l'amplitude est dans ladite plage, la commande d'un dispositif d'avertissement destiné à indiquer que le pneumatique est dégonflé partiellement ou totalement.

10. Procédé selon la revendication 9, caractérisé par la comparaison supplémentaire des signaux non corrigés de chacune des quatre roues tour à tour avec les signaux non corrigés de chacune des autres roues, la détection du moment où l'un des signaux est différent de la moyenne des quatre autres signaux de plus de 0,1 % et, lorsque ces signaux sont présents, l'indication du fait que le pneumatique est dégonflé partiellement ou totalement.

11. Procédé selon la revendication 9, caractérisé en ce que les signaux sont corrigés l'un par rapport à l'autre d'après les constantes dérivées par déplacement en ligne droite du véhicule à une seule vitesse.

Fig.1


WHEEL
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